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Project Acronym: PyrTreelineMod

Project Full Name: A model for Pyrenean Treeline: from individuals to landscapes under a changing climate

Marie Curie Actions

FINAL PUBLISHABLE SUMMARY REPORT

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Over the last years the interest in tree line ecology has increased considerably, given the high vulnerability of mountain ecosystems to global change. Tree line ecotones are one of the best indicators of climate change, providing a registry of recent Earth history. In the last decades, advancing tree lines have been observed worldwide, a response which has been attributed mainly to anthropogenic climate change. For example, a recent work by Harsch et al. (2009) *Ecol. Lett.* showed that abrupt tree lines are less likely to advance in response to climate change than gradual tree lines. An upward shift of forests would have important implications by increasing the terrestrial carbon sink and by reducing the availability of habitat for endemic or endangered alpine plants. However, there is a controversy about the mechanisms underlying the formation of tree lines, and the emergence of different tree line physiognomies. This is a major limitation for predicting the future evolution of tree lines under projected climate scenarios for this century. In this context, the project *PyrTreeLineMod* was proposed to improve the understanding of tree line dynamics and to apply this insight to predict its future evolution, with a main focus on the Pyrenean range.

A first major achievement of the project was the development a spatially explicit and Individual Based Model (IBM hereafter) considering the basic demographic processes and ecological interactions (e.g., competition for resources, recruitment, facilitation, etc), as well as the environmental constrains necessary for the formation of tree lines. The model was trained against real data, using observations from four tree lines along the Pyrenean range encompassing a variety of physiognomies. Models of varying complexity were assessed in order to identify the minimum set of mechanisms necessary for the emergence of different tree line physiognomies. My results provide a clear, simple explanation of the different responses observed at different tree line sites in the context of recent climate change. I found that the position of abrupt tree lines is more likely to be growth limited and that of gradual tree lines are more likely to be mortality limited. If mortality constrains tree line position, we would expect that a change to more favorable conditions at higher altitudes would cause an advancement of the tree line due to increased tree survival.

The analysis of IBMs is a challenging task, especially when the objective of the study requires a confrontation of model output with real-world data. Concurrently to the analyses described above and to surpass the limitation of the standard procedures employed, I developed a novel approach for the analysis of IBMs. In this way, I have pioneered the combination of Bayesian methods with model selection procedures for the parameterization and selection of relevant processes in IBMs. This novel approach resulted in a series of technical advantages, including improved efficiency in model fitting (both in terms of the quality of estimates and in computer time), and in the assessment of model uncertainty. In this way, my approach takes full advantage of the Bayesian approach to estimate uncertainty in model parameters and to propagate this uncertainty to model estimates and projections. Given the huge output derived from this kind of analysis, a set of dedicated software programs and routines were developed during the project. The development and fitting of the IBM was a key task that had to be completed before the biological questions of the project could be investigated. This stage was especially challenging and more time-consuming than initially estimated; most simulations required simulation times of more than one month in the department computer cluster and continuous probes and error checking were necessary to obtain confident results.

The ability of the model to reproduce real world patterns encouraged the development of extensions considering other kind of scenarios. I modified the model to study the dispersal of the population after a release from the limiting conditions setting the forest edge. The idea was to assess the ability of tree line populations to respond to climate change. A consistent result from this set of simulations was the observation of three clearly defined phases. First, there is a local increase in tree density with no tree line advancement. This delay in the onset of tree migration can last even for three decades, and is followed by a second phase of slow advancement of the tree line. Only nearly a century after the release, there is a sudden increase in the speed of the advancement of the population. These results have important implications for the management of tree lines in a near future. They indicate that the advancement of the tree line can be delayed, and it provides an explanation for observations of increased tree densities with no tree line migration in recent decades in the Pyrenees.

A next step in the project involved the question of how these dynamical constraints may influence the distribution of Pyrenean tree lines in a near future at wider scales. For this purpose, I combined the theoretical results regarding tree line migration with a habitat model. To this end, I compiled a spatially explicit database in a Geographical Information System (GIS). The database considers current climate conditions (1970-2000) and projections for this century from the PRUDENCE project (http://prudence.dmi.dk/). The database also includes a detailed digital elevation model based on data retrieved by the satellite ASTER, and derived variables like the aspect and the slope. The analyses I conducted indicated that *P. uncinata* distribution is conditioned by summer conditions. Climate projections both from PRUDENCE and from the IPCC AR4 models for the Pyrenees indicate that this is the season in which climate change impacts will be more important (e.g., mean temperature increases of 3ºC and 20% reduced precipitation).

In a final step of the project, I investigated changes in individual tree growth at four Pyrenean tree lines. One of the main predictions of the IBM model is that individual growth is a key process in setting the forest limit, so a better understanding of how climate variables influence tree growth can provide further insight for projecting the response of tree lines to climate change. I proposed for the first time, the application of the principles of the metabolic theory for the analyses of tree growth, and to project the effects of climate change on this process. To this end I gathered data on individual growth from dendrochronological analysis and historical climate series. Preliminary analyses indicate that both increased temperatures and precipitation enhance tree growth, and work in progress will elucidate the result of the interaction of both factors on tree growth during this century.